

Advanced Development of a Laser Bathymetry System: L-Bath

Jules S. Jaffe

Marine Physical Lab, Scripps Institution of Oceanography, La Jolla, CA 92093-0238
phone: (858) 534-6101 fax: (858) 534-7641 email: jules@mpl.ucsd.edu

Karl D. Moore

Marine Physical Lab, Scripps Institution of Oceanography, La Jolla, CA 92093-0238
phone: (858) 822-1729 fax: (858) 534-7641 email: kdmooresmpl.ucsd.edu

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<http://pandora.ucsd.edu>

LONG-TERM GOALS

The long range goals of this program fall into several areas: 1) Operational, 2) Scientific, 3) Computational. In an operational sense, we seek to demonstrate the feasibility and field deployable ability of a new type of 3-dimensional underwater imaging system which is based on using solid state components instead of mechanical ones. In a scientific sense we seek to understand the propagation of light in the coastal environment in which this imaging system will operate. This will include the deployment of the system in the COBOP field program and will take advantage of the large amount of auxiliary data that will be collected in this program. In a computational sense, we seek to develop processing algorithms to optimize the quality of information that is being sensed optically. Using the output from the solid-state imaging array, we will be able to construct a record of the time varying radiance that is incident upon the camera. Using this information in conjunction with the environmental data that will be collected, we will test the system's capability to simultaneously estimate both the environment and also the reflectivity and topography of the bottom, especially with respect to finding man made items.

OBJECTIVES

The objective of this past year of our program has been to continue our studies with our existing instrumentation to expand, develop and explore the use of the system. Data from past field operations has been analyzed and new algorithms for processing the information have been created.

APPROACH

Our technical approach for the advanced development of the system has been to continue characterizing the capability of the system to image three dimensional objects on the sea floor. Algorithms will be tested on data sets that were collected under very precisely controlled situations in our lab and then generalized to the field data sets which were collected during the field expeditions.

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WORK COMPLETED

A rigorous absolute calibration methodology has been derived for high-resolution 3D mapping laser line systems. The method is iterative and only requires a scan of a fixed target in air and water for complete bathymetric parameterization.

Contrast performance of the system in varying degrees of turbidity has been investigated. The influence of in-water radiometric issues, such as target reflectance, beam spreading (point spread function) etc., on bathymetric accuracy have also been investigated.

The design feasibility for a new extended range laser line scan system for use on an AUV has been researched.

RESULTS

Calibration: An absolute bathymetric calibration was theoretical derived for a generic family of laser line scanning systems that use an imaging array as the receiver. This calibration has also been applied specifically to the *3D Sea Scan* instrument configuration where its orthogonal layout (between source-receiver window ports, coplanar scanning and viewing fields etc.) results in a high degree of accuracy in iteratively determining specific optical component parameters within the system. The calibration method has been tailored for application in the ocean-going environment with the data required for calibration being acquired from scanning a target at fixed range in air and in water. The method uses the refractive index of sea water to modulate the triangulation parameters used to calculate depth rather than redeploying the system for alternative target ranges.

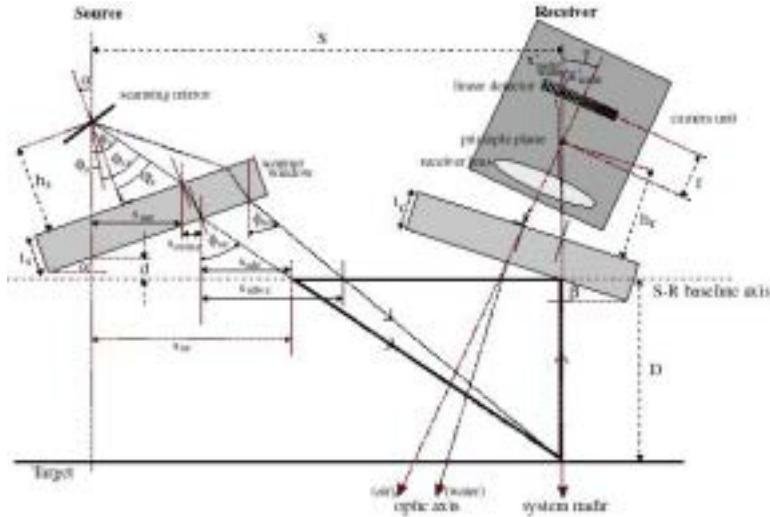


Fig. 1. Configuration parameters for generic description of 3D mapping laser line scan systems using a solid-state imaging array as receiver.

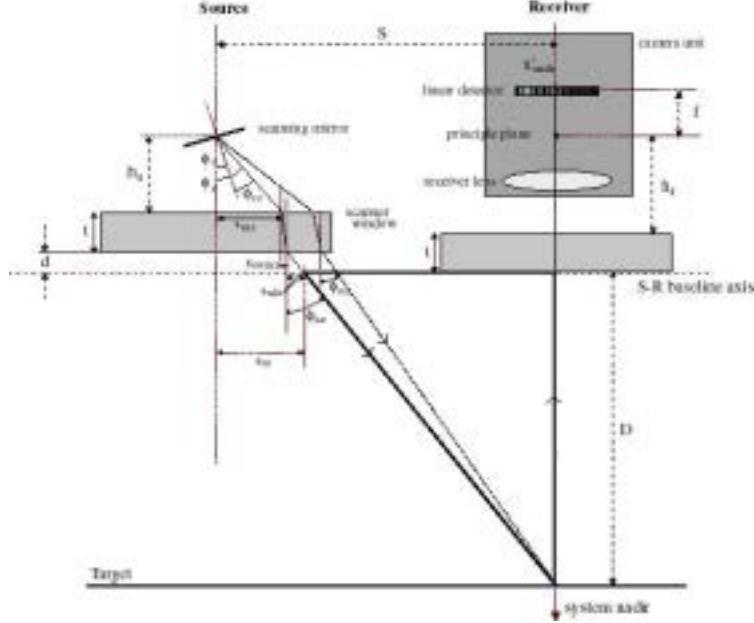


Fig. 2. Parameters used in the orthogonal 3D Sea Scan configuration.
Depth range can be calculated for the 3D Sea Scan system for in water data using the relation,

$$D_{w_j} = - \frac{s_{w_j}}{\tan \left(\sin^{-1} \left(\sin(\phi_o + kv_j) \left(\frac{1}{\eta_w} \right) \right) \right) - \left(\frac{(p_{w_j} + ro_{wp_j}) - p_{wnadir}}{\eta_w f} p_{pitch} \right)}$$

where the laser beam angle is expressed in terms of the scanner's mounting angle in the system ϕ_o plus the galvanometric deflection angle $\phi_{sj} = kv_j$. p_{w_j} is the pixel position of the target spot image on the array, ro_{wp_j} is the roll-off correction applied to pixel p_{w_j} , p_{wnadir} the pixel corresponding to the pixel that images directly below the system, p_{pitch} the pixel pitch or pixel center-to-center spacing, f is the focal length of the receiver optics and η_w is the refractive index of water.

In Fig. 3 the predictive capability of the calibration can be seen. Here, a flat target has been placed parallel to the source-receiver axis at 3 known ranges, and scanned in both air and water. Actual target ranges are separated by 25 cm. Absolute depth has been shown to be within a few millimeters across the scanning field of view at roughly 2.7 m range.

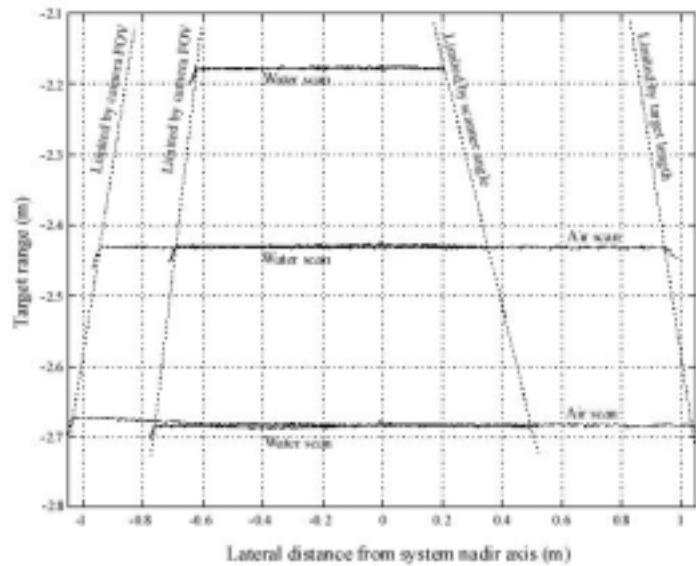


Fig. 3.

Contrast enhancement: Image processing techniques were developed to increase signal-to-noise in the images via a binning procedure. Results were characterized via image contrast. For example, in Fig. 4 the contrast of a black stripe on a white background is shown for 6 turbidity levels as a function of binning. The graph indicates that binning laser spot image pixels is only advantageous when the noise floor of the detector is approached, whereas use of the single centroid pixel yields the best image quality when there is adequate return signal.

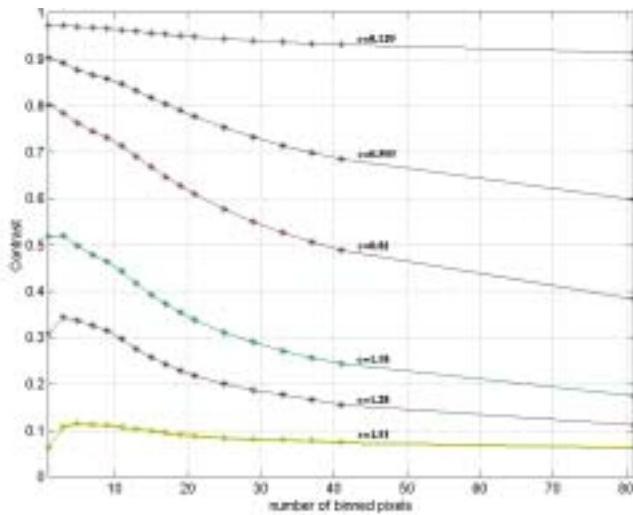


Fig. 4. Contrast as a function of pixel binning at different turbidities for black stripe on white background.

Development of a new extended range imaging system: As part of our activities this year we have been developing a proposal for a new extended range imaging system for operation onboard an AUV. The design of the proposed instrument has been developed based on the lessons learned from its predecessors; *L-Bath* and *3D Sea Scan*. Progress in design considerations, particularly in how they relate current state-of-the-art technology and the requirements of a small, low-power, robust imaging system, have been guided by the pros and cons revealed in the laboratory and field testing of the *3D Sea Scan* system. It is envisioned that the new system will provide at least an order of magnitude improvement in sensitivity and perhaps 2-3 orders of magnitude increase in acquisition rate. This is accomplished by the use of an array of photomultiplier tubes and a scanning high power laser beam. The design also overcomes any alignment concerns between source and receiver that were tantamount to success in the past and should be operational in both daylight and night.

IMPACT/APPLICATIONS

To our knowledge, we have developed the most detailed three dimensional system for viewing objects at extended range in the sea using light. The system demonstrates that extended range imaging can be achieved by using structured lighting techniques. Potential future areas for the use of the system are for studying benthic systems, including bottom turbulence induced by bottom roughness.

TRANSITIONS

Since this is a technology development program we have been in contact with companies that are interested in our work. In addition, we have demonstrated our results to personnel at the Naval Coastal Systems Center in Panama City, FL.

RELATED PROJECTS

We are currently involved in a program that has been sponsored by the acoustics, biological oceanography and geology division of ONR to scatter sound from the sea floor. A 10 day deployment there resulted in the observation of bottom bathymetry to submillimeter resolution with time intervals as short as minutes.

PUBLICATIONS

Moore, K. D. , J. S. Jaffe and B. L. Ochoa, "Development of a New Underwater Bathymetric Laser Imaging System: L-Bath, J. Atm. and Oceanic Technology, 17, pp 1106-1117, 2000.

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